**REPORT FOR OBJ1.TASK 4a: DESIGN/SCHEMATIC LEVEL SPECIFICATIONS FOR SOILS, AND TREE PLANTING**

To: MPCA

From: The Kestrel Design Group Team (The Kestrel Design Group Inc, with Dr. William Hunt, PE and Ryan Winston, PE - North Carolina State University, Dwayne Stenlund – Minnesota Department of Transportation, James Urban – Urban Trees and Soils)

Date: October 31, 2013

Re: Contract CR5332

**SCOPE: note, this report addresses soils, please see separate report for tree planting**

Develop separate design specifications for tree quality, soil characteristics (quality and volume) for tree BMPs, and tree planting.[[1]](#footnote-1) Where appropriate the design specifications shall include but not be limited to considerations of BMP type (e.g. open, closed, or partially-open tree pits), soil properties, cold climate, water volume and pollutant (phosphorus and total suspended solids) removal, tree species, and groundwater constraints (e.g. seasonal high water table, karst settings). The specifications shall include illustrations and design drawings:

* 1. For each design specification (tree quality, soil characteristics, and tree planting), review state-of-the-art literature to identify existing design specifications, design drawings and illustrations for tree BMPs, considering different variations of tree BMPs.
  2. Review literature and identify special design considerations and incorporate these into design specifications for tree quality, soil characteristics, and tree planting. Examples of these specifications include but may not be limited to soil suitability, cold climate considerations, groundwater considerations, and need for stormwater pretreatment to remove pollutants.
  3. Prepare and submit a Technical memo that includes design specifications for tree quality, soil characteristics, and tree planting, including graphics. Include CAD drawings illustrating design specifications.
  4. Prepare and submit a final report that provides design specifications for tree quality, soil characteristics, and tree planting, including graphics. Include CAD drawings illustrating design specifications.

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**REPORT FOR SOIL QUALITY AND VOLUME SPECIFICATIONS (SEE SEPARATE REPORT FOR TREES)**

1. **Soil Volume Specification**
2. **Summary of Research on Minimum Soil Volumes Needed**

As summarized in Task 2, providing adequate rootable soil volume is crucial to growing healthy trees. Several researchers have investigated minimum soil volumes needed to grow healthy trees. Table 4.1 summarizes the results of a number of studies worldwide of minimum soil volumes needed to grow large, healthy trees.

**Table 4.1: Summary of results of studies analyzing minimum soil volume needed by trees**

|  |  |  |
| --- | --- | --- |
| **Reference** | **Reference’s Recommendation** | **Notes** |
| Lindsey, P. and N. Bassuk. 1991. Specifying Soil Volumes to Meet the Water Needs of Mature Urban Street Trees and Trees in Containers. Journal of Arboriculture 17(6): 141-149. | **2 c.f. soil/ 1 s.f.** crown projection | Developed a method to calculate tree soil volume needs **based on tree water use** (total tree canopy area, leaf area index, pan evaporation, soil available water holding capacity, and rainfall frequency) |
| Kopinga, J. 1991. The Effect of Restricted Volumes of Soil on the Growth and development of Street Trees. Journal of Arboriculture 17(3): 57-63 | Need **1500 cf.** rootable soil volume for large tree; trees with only 10 m3 (353 c.f.) “reach the limits” in 10 to 20 years. | Based on **calculated nitrogen demands of trees** and **field surveys** |
| Bakker. J.W. 1983. Groeiplaats en watervoorziening van straatbomen. Groen, 39(6)205-207; OBIS, 1988. Bomen in straatprofielen – Voorbeelden – Groeiplaatsberekening. Uitgeverij van de Vereniging van de Nederlandse gemeenten, ‘s-Gravenhage 1988. 63 p. Cited in Kopinga 1991. | **2.5 c.f**. rootable soil of **reasonable qualit**y**/ 1 s.f.** crown projection, reasonable soil defined as medium coarse sand with organic matter content 3-7%; later added that **1.7 c.f**. rootable soil/**s.f.** canopy suffices if the soil is of **good quality** (defined as medium coarse sand with organic matter content of 7 to 8%) | Based on his **research** of **water consumption** of containerized trees and **field surveys** |
| Kent, D., S. Shultz, T. Wyatt, and D. Halcrow. 2006. Soil Volume and Tree Condition in Walt Disney World Parking Lots. Landscape Journal 25:1–06 | Minimum soil volume requirements species dependent, but in general, **1,500 c.f.** was required to ensure that a Disney tree would be in good condition, and 1000 c.f. of soil for a 95% chance that a tree would be in good condition | Based on **survey** of tree condition vs soil volume of 1,127 parking lot trees at Disney World |
| Schoenfeld, P.H. 1975. De groei van Hollandse iep in the kustprovincies van Nederalnd. Nederlands Bosbouw Tijdschrift 47:87-95. Cited in Kopinga 1991 | Roadside Dutch elms grew best if provided at least 45 m3 (**1589 c.f**.) or more soil; growth always bad with less than 10 m3 (353 c.f.) | Based on **field surveys** in the Netherlands |
| Schoenfeld, P.H., J. van den Burg. 1984. Voortijdige bladval en groeiafname bij ‘Heidemij’populier in beplantingen langs autowegen. Nederlands Bosbouw Tijdschrift 56:12-21. Cited in Kopinga 1991. | Roadside poplars about 20 years old grew best if provided at least 50-60 m3 (**1766-2119 c.f.**) rootable soil | Based on **field surveys** in the Netherlands |
| Helliwell, D.R. 1986. The Extent of Tree Roots, Arboriculture Journal 10:341-347; updated in Letter to the Editor Arboricultural Journal: The International Journal of Urban Forestry, [Volume 16](http://www.tandfonline.com/loi/tarb20?open=16#vol_16), [Issue 2](http://www.tandfonline.com/toc/tarb20/16/2), 1992. | Soil volume about equal to one-tenth of the volume of  its live canopy; **2.23 c.f. soil per s.f canopy** | Rule of thumb based on **field investigations** for average climate of southeast England |
| Urban, J. 1992. Bringing Order to the Technical Dysfunction Within the Urban Forest. Journal of Arboriculture 18(2): 85-90 | **1 to 3 c.f. soil/ 1 s.f. crown projection** | Graph of soil volume required vs. Tree Size, synthesized from several papers attempting to establish the relationship between tree growth and soil volume (Lindsey and Bassuk 1991, Perry 1985, Perry 1989, Urban 1989) |

Minimum soil volume needed to grow healthy trees has been studies several ways, including:

* Field surveys investigating minimum soil volumes that grew healthy trees
* Calculation of minimum soil volume needed based on tree water requirements.
* Calculation of minimum soil volume needed based on tree nitrogen requirements (Kopinga 1991).

Each of the above techniques listed above appears to indicate about the same range of minimum soil volume needed:

* 1 to 3 cubic feet of soil per square foot of canopy
* 1000-2100 cubic feet of soil for a large tree (median of 1500 cubic feet and mean of 1506 cubic feet)

To put these numbers in perspective in relation to tree size and typical street tree spacing:

* Using the above numbers, a tree with 2 cubic feet of soil per square foot of canopy would need 1413 cubic feet of soil to grow 30’ wide.
* Assuming 2 cubic feet of soil per square foot of canopy, 1,500 cubic feet of soil would be able to support a 31’ wide tree.

1. **Minimum Soil Volume Standard Precedents**

Because of the importance of providing adequate rootable soil volume to grow healthy trees (see Task 2), several jurisdictions have enacted minimum soil volume policies (see Table 4.2 for examples).

Table 4.2: examples of jurisdictions with minimum tree soil volume requirements

|  |  |
| --- | --- |
| **Jurisdiction** | **Minimum Tree Soil Volume** |
| Kitchener, Ontario, Canada | * Large stature trees (≥24” diameter at maturity): 1589 c.f for single trees; 1059 cf for trees sharing soil volume; 530 c.f. allowable shared soil volume * Medium Stature trees: (≥16” diameter at maturity): 989 c.f for single trees; 653 cf for trees sharing soil volume; 336 c.f. allowable shared soil volume * Small stature trees: (≥8” diameter at maturity): 600 c.f for single trees; 389 cf for trees sharing soil volume; 212 c.f. allowable shared soil volume * For all boulevards where trees are planted, the minimal soil depth will be 450 mm (17.7 inches), and all other soil habitat zones (public/private front lawn, cul de sac, active parkland) will be 900 mm. * Where soil habitats zones (e.g. boulevard and front lawn) must be connected to achieve the required soil volumes, root pathways or Silva Cells will be used to provide a functional connection between the two areas. |
| Emeryville, CA | * 600 cubic feet (17 cubic meters) for a small tree * 900 cubic feet (25 cubic meters) for a medium tree * 1200 cubic feet (34 cubic meters) for a large tree * 50% credit for planting areas under adjacent paving using 100% planting soil with Silva Cell or similar products. |
| Toronto, Ontario, Canada | * 30 cubic meters (1059 cubic feet) of soil per tree * 20 cubic meters (706 cubic feet) per tree for trees with shared volume * Minimum 0.9 m (3’) and maximum 1.2 m (4’) depth |
| Markham and Oakville, Ontario, Canada; Burnaby MetroTown Development Area, British Columbia, Canada | * 30 cubic meters (1059 cubic feet) of soil per tree * 15 cubic meters (530 cubic feet) per tree for trees with shared volume |
| North Vancouver Lonsdale Street Guideline, British Columbia, Canada | * 15 cubic meters (530 cubic feet) per tree for trees with shared volume |
| Calgary, Alberta, Canada | * Provide for a volume of soil suitable for a 25 year tree life span, this is approximately 14 cubic meters [494 c.f.) for a single tree. An additional 7 cubic meters [247 c.f.] of soil is required for each additional tree in interconnected plantings |
| Langley, British Columbia, Canada | * Zoning Bylaw requires 10 cubic meters (353 cubic feet) of growing medium per tree planted in hard surfaced parking lots on private developments. * Subdivision and Development Servicing Bylaw requires 10 cubic meters (353 cubic feet) of growing medium per tree (generally street trees) * growing medium defined as screened, weed free, composted soil mixed according to BC Landscape Standards for the intended use and confirmed with a soil analysis report. * In hardscape environments, street trees are expected to be planted using structured supports such as Silva Cell to achieve the expected growing volume |
| Winnipeg, Manitoba, Canada, Tree Planting Details and Specifications, Downtown Area and Regional Streets | * 8.5 cu.m. (300 c.f.) to 12.75 cu.m. (450 c.f.) of soil per tree * 17.0 cu.m. (600 c.f.) to 25.5 cu.m. (900 c.f.) per tree for trees with shared volume * Optimal planting medium depth 900mm (36in.). Minimum planting medium depth of 760mm (30in.) will be accepted where 900mm is not feasible. |
| Denver, CO | * Internal standard: 750 c.f. of soil volume per tree |
| University of Florida Extension Recommendations (Urban Design for a Wind Resistant Forest) | * Small trees (shorter than 30’) = 10’x10’x3’ = 300 c.f. * Medium trees (Less than 50’ height or spread) = 20’x20’x3’ = 1,200 c.f. * Large trees (Greater than 50’ height or spread) = 30’x30’x3’ = 2,700 c.f. |
| Minnesota B3 Guidelines | * Small trees (e.g. serviceberry) = 400 c.f. * Medium trees (e.g. ironwood) = 800 c.f. * Large trees (e.g. hackberry) = 1,200 c.f.   If using structural soils, total soil volumes above need to be multiplied by 5 to obtain equivalent volume of soil useable by the tree. |

1. **Research Comparing Value of Rock Based Structural Soil to Traditional Tree Soils**

Research that compares rock based structural soil to loam soil indicates that significantly larger soil volumes are needed to produce the same size tree using structural soil vs. loam soils.

Based on plant available water holding capacity alone, it would appear that approximately 1.5 times the amount of CU structural soil is needed as needed to grow the same size tree growing in sandy loam (Bassuk 2010).

However, a pot study that compared growth of trees in CU structural soil to trees growing in loam indicates that tree growth in CU structural soil vs. loam soil is likely limited by more than just plant available water holding capacity, as the pot study found that 5 parts of structural soil were needed to provide the soil value of 1 part of loam soil (Loh et al, 2003). The pot study compared the growth of fig trees in structural soil and loam soil in pots over 500 days. Tree growth was compared in the following soil types and volumes:

* 0.4 c.f. of loam soil (small loam soil)
* 0.4 c.f. of structural soil(small structural soil)
* 2 c.f. of loam soil (large loam soil)
* 2 c.f. of structural soil (large structural soil)

There were no significant differences in above ground growth between trees in the small loam soil pots and the ones in the large structural soil, indicating that 5 times the amount of structural soil was needed to produce the same size tree grown in the small loam soil. As only 1/5 of structural soil is composed of soil, it appears that perhaps only the soil component of the structural soil is useable to the tree as growing medium. Longer term studies are recommended to confirm the exact proportion of structural soil needed to provide the value of 1 cubic foot of loam soil.

A study by Bartlett Tree Research Laboratories is finding that trees growing in loam soils in suspended pavement are growing better than trees grown in rock based structural soil (Smiley et al 2006, Smiley 2013). Since 2004, they have been comparing tree growth in natural soil under suspended pavement compared to growth of trees grown using other ways to prevent rooting volume compaction under pavements: stalite soil, and gravel soil (ie structural soil), as well as to trees grown in compacted soil. Each tree was provided 5.7 m3 (200 cubic feet) of rooting space. Throughout the 9 years since the trees were planted, Elm growth (trunk diameter and tree height) has been best in the suspended pavement with natural soil (see Figures 4.1-4.4).

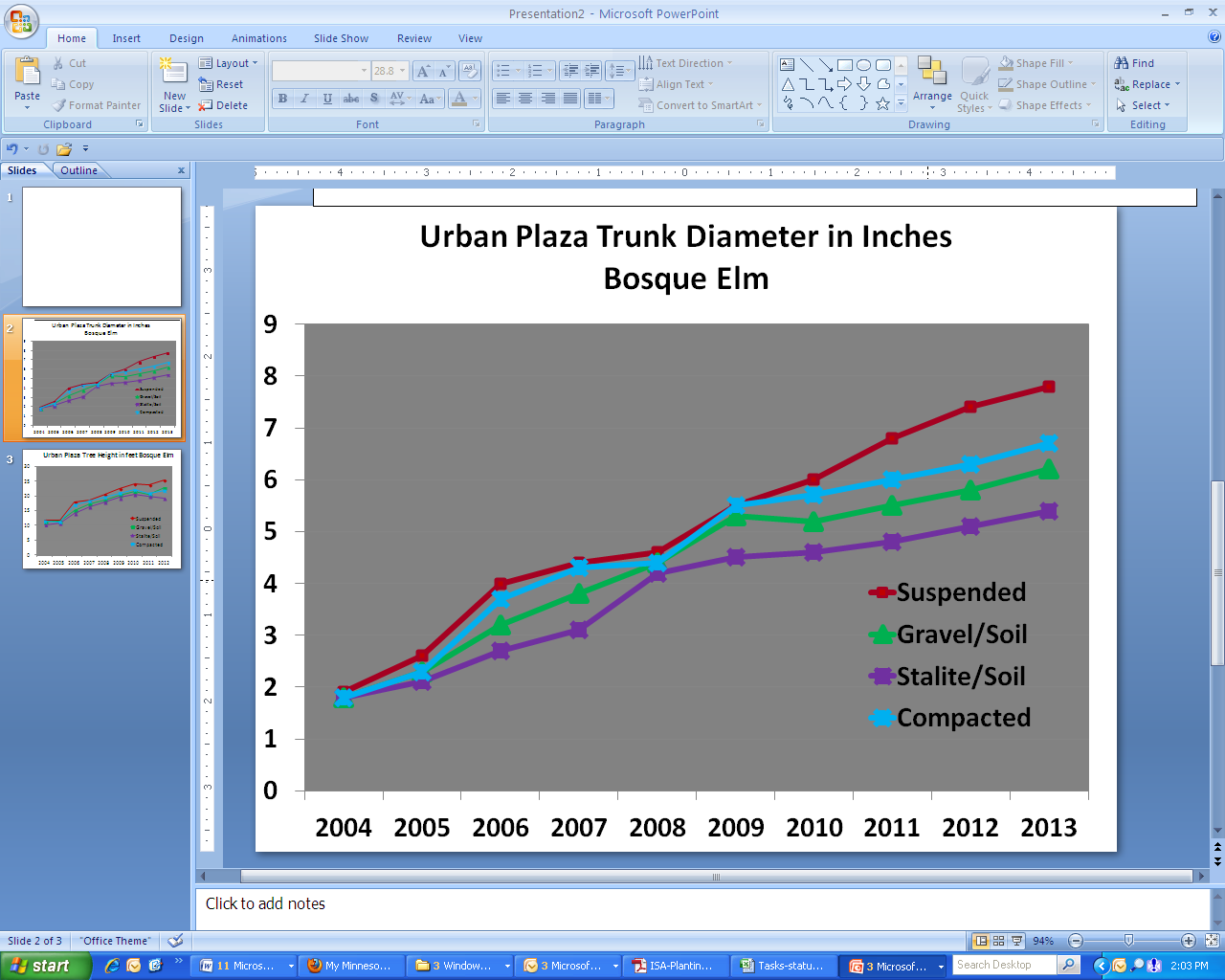


Figure 4.1: Trunk diameter in inches of Bosque Elm grown using various planting techniques (Smiley 2013)

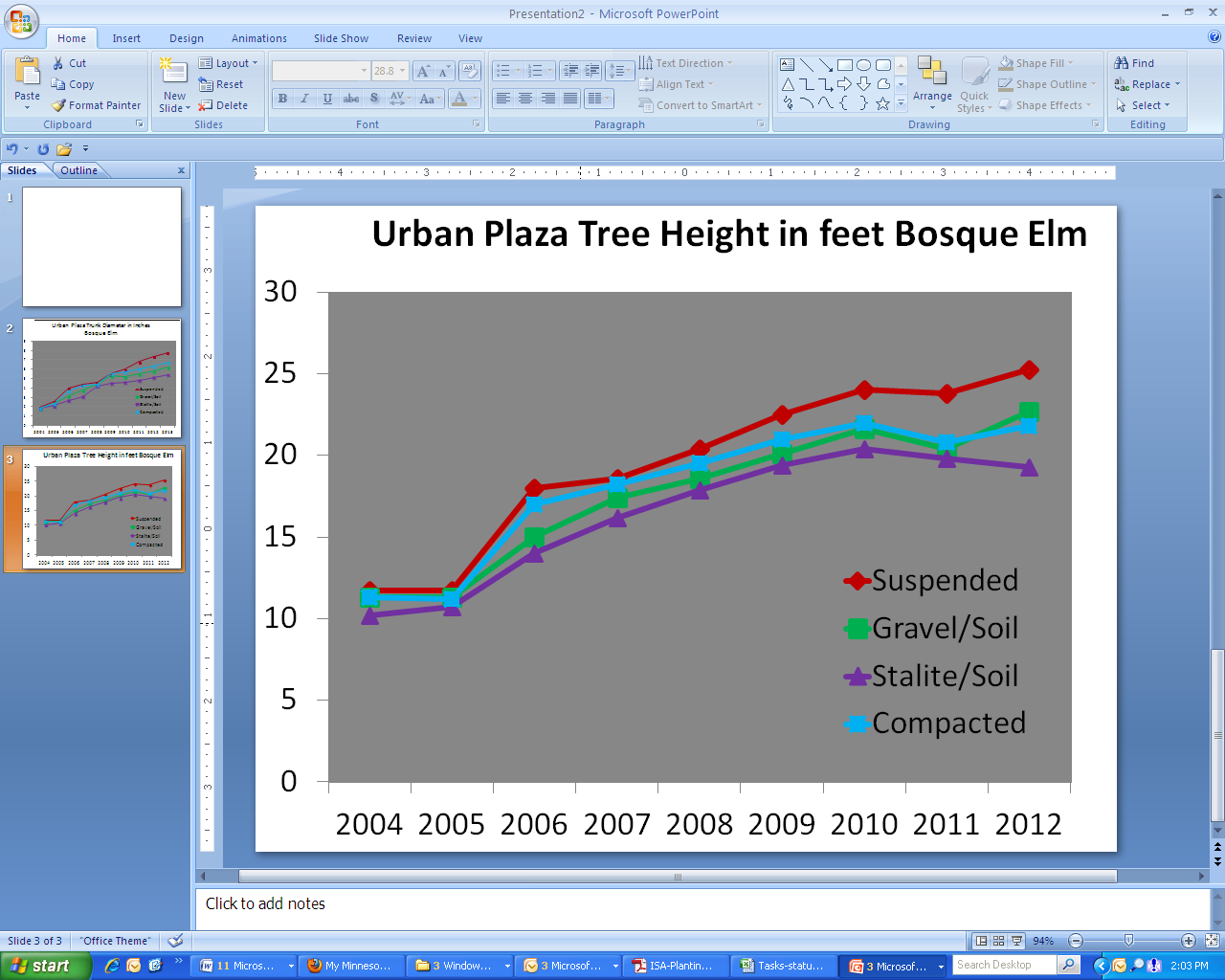


Figure 4.2: Height in feet of Bosque Elm grown using various planting techniques (Smiley 2013)

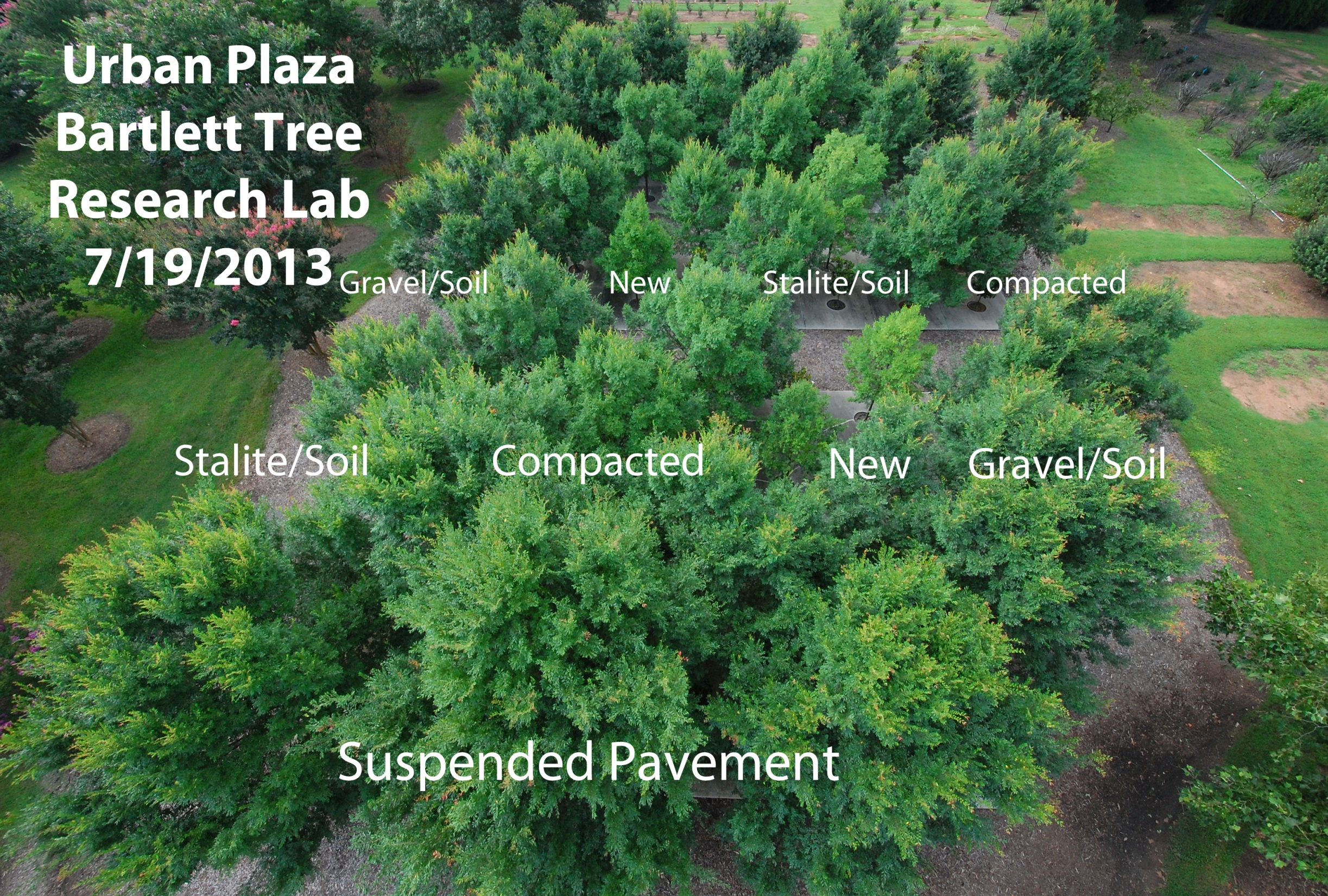


Figure 4.3: Overview of Bartlett’s study comparing trees grown using various planting techniques (Smiley 2013)

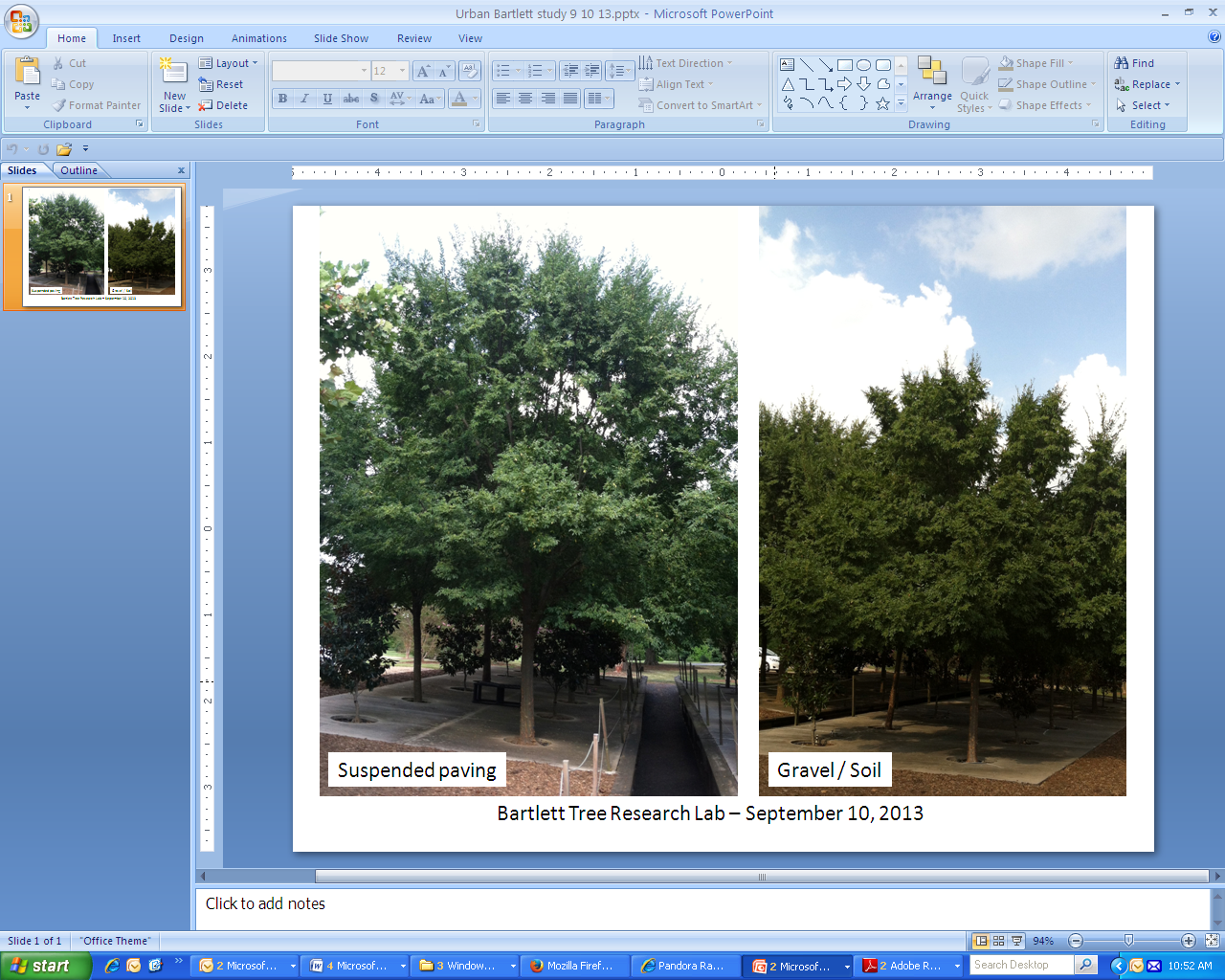


Figure 4.4: Side by side comparison of suspended pavement and structural soil trees in Bartlett’s study (Smiley 2013)

1. **Recommended Minimum Soil Volume Requirements for MIDS credit for Urban Trees for Stormwater**

Based on the research summarized above, we recommend requiring a minimum of 2 cubic feet of rootable soil volume per square foot of mature tree canopy size. Where rock-based structural soil is used, the rock component of the rock based structural soil should not be included in the soil volume calculation. For example, if a rock based structural soil is used that contains 80% rock and 20 % soil, only the 20% soil component counts toward the soil volume requirement, i.e. 5 cubic feet of this rock based structural soil would be needed to provide 1 cubic foot of useable soil.

1. **Soil Quality Specification**

At this time, most LID manuals only address trees in traditional bioretention practices, i.e. they do not provide separate soil specifications for systems that use only urban trees (i.e. without herbaceous vegetation.) In nature, trees typically grow with herbaceous vegetation in the same soils, but generally drier climates have fewer trees (i.e. more areas of herbaceous vegetation without trees) than wetter climates. I.e. in general tree soils need more moisture holding capacity than soils that just support herbaceous plants (depending on the tree and herbaceous species).

Manufacturers of proprietary tree Stormwater BMP’s such as, for example, Silva Cells tree soil systems and CU structural soils, provide recommendations for soils to be used in their systems (see Task 5 for of those systems).

The Puget Sound manual has a separate section on Urban trees (Hinman and Wulkan 2012) and provides some guidance on soil quality and volume for trees, but does not include a soil specification for urban trees.

Many jurisdictions have their own soil specifications for urban tree planting that are not specifically targeted towards stormwater management and provide excellent guidance regarding tree needs.

Many books about trees and soils also address what trees need in soil, such as, for example, Urban 2008.

The goal of this draft report is to synthesize existing literature and research on soils designed to optimize tree growth and soils designed for optimized bioretention function.

1. **Literature review of soils optimized for Tree Growth**

Examples of soil guidelines and specifications for optimized tree growth include the following:

**Toronto Street Trees. Guide to Standard Planting Options. 2010. City of Toronto Urban Design Streetscape Manual. In collaboration with Parks, Forestry & Recreation**. Downloaded September 2013 from:

<http://wx.toronto.ca/inter/plan/streetscape.nsf/d2ee0d49ba602f3e85257457005a208d/491C15A190DCC0A7852576EB0066D3C5/$file/T-G-TreeGuide.pdf>

High-quality soil shall consist of a minimum 0.9m and maximum 1.2m depth, over and above any required drainage system and/or granular material, be uncompacted, and be sandy loam with the following composition:

Sand (50%-60%)

Silt (20%-40%)

Clay (6%-10%)

Organic (2%-5%)

pH = 7.5 or less

**DTAH et al 2013 tree manual for Toronto:**

Recommends:

* pH 6.0 to 7.8
* Drainage rates of between 12 mm and 75 mm per hour are considered optimum. Drainage rates must be measured in the field, however, soil can be tested in the lab if it is compacted to a prescribed density.
* Soil organic matter should be between 3% and 5% dry weight in the upper layer of the profile at the time the soil is installed. Organic matter in the lower soil level should be between 1.5% and 3% dry weight. This difference can be accomplished by making two different soils or simply tilling additional compost into the surface of the soil.
* See pages 56-62 for detailed conceptual explanation of other tree soil requirements, including, for example, the importance of soil structure and obtaining unscreened soil with soil ped structure intact, recommendations for soil mixes and proportion of coarse to medium sands; difference between natural soil organic matter and compost.

**Urban 2008 book about urban trees: Up by Roots: Healthy Soils and Trees in the built environment**

* Contains extensive explanations of tree soil needs
* Some of the relevant highlights include:
* “The goal is to develop a soil that has good drainage capability, while providing adequate moisture and nutrient holding capacity for the plants.”
* “When sand is added to a soil, be sure that the final coarse to medium size sand content exceeds 50 percent. At lower amounts of sand, drainage rates are not increased.”
* “As the sand and aggregate content increases above 55 percent, the water-and nutrient holding capacity goes down and the drainage rate goes up.”
* “High sand content soils are reliably drained and more tolerant of a wide range of compaction rates. These soils are less likely to become over compacted, but require a continuous supply of water and nutrients, which increases maintenance.” [*comments from Kestrel team: directing stormwater to these soils lessens this problem because it increases water and nutrient supply, though the trees will likely still be exposed to periodic droughts*]
* “As the sand is reduced in the mix, close to the 55 percent threshold, compaction rates become critical. Too much compaction, and the drainage rates in finer-grained soil slow to unacceptable levels. Too little compaction in finer grained soil and soil settlement can unacceptable. The window between too much and too little compaction is hard to manage during construction.”
* “Soil mix design is a multi-step process and does not end with the publication of specifications. The specifications should set performance standards and the types of mix components to be used. At the time of writing the specifications the designer cannot know the actual source of the soil or organic amendment. Minor variations in these materials will change the mix proportions.”
* “Testing of the soil to be used in the mix must include the measuring of the difference sizes of sand particles, known as sand fractions.”

“A good measure to evaluate the performance of a soil mix is its infiltration rate when compacted to a known level. A developing standard is to test infiltration at 80 and 85 percent of maximum dry density as measured by the Proctor test.”

1. **Literature review of soils optimized for bioretention**

Using trees as stormwater BMP’s adds the following soil requirements to those of traditional street trees that are not planted for stormwater management:

* As more stormwater is directed to the trees, there is more danger of soils clogging, so limiting the fines content of the soil becomes more crucial. However, research shows that while the hydraulic conductivity of a bioretention practice typically decreases initially, hydraulic conductivity goes back up as plants and microbes improve soil structure over time and infiltration rate does not decrease significantly long term (Hatt et al 2009, Jenkins et al. 2010, Li & Davis 2008b, Barrett et al 2011).
* Where nutrient reduction in stormwater runoff is a goal, limiting nutrient content of the soil is required to minimize nutrient leaching from the soil.

A representative sampling of the most recent and comprehensive literature on bioretention media guidelines is summarized below.

**North Carolina Bioretention Soil Specification (**referenced e.g. in North Carolina Department of Environment and Natural Resources. 2009. Stormwater BMP Manual Chapter 12: Bioretention. Revised 07-24-09. <http://portal.ncdenr.org/c/document_library/get_file?uuid=199a62d4-3066-4e24-a3f1-088c6932483a&groupId=38364>)

* One of the most widely used bioretention media specifications in the US (i.e. several other states have also adopted it).
* May clog more easily in northern climates where de-icers are used (Bannerman 2013, personal communication). [Note from Kestrel team: recommend research to see if flushing salts out of the soil in spring with water eliminates SAR effect).
* North Carolina’s bioretention standards recommend incorporating trees in all bioretention practices except for grassed cells: “A minimum of one (1) tree, three (3) shrubs, and three (3) herbaceous species should be incorporated in the bioretention planting plan unless it is a grassed cell.”
* Although there is some concern among tree specialists that this soil may have too little organic matter to grow healthy trees, this soil has been used extensively to grow trees with success in North Carolina (Winston and Hunt, 2013, personal communication). North Carolina does receive more annual precipitation than Minnesota, so moisture retention is more crucial in Minnesota than in North Carolina and tree may not perform as well in Minnesota as in North Carolina in a soil with low moisture content. Research by Fassman et al (2013), however, indicates that sand based bioretention media can have as much plant available water as horticultural soils with less sand and more organic matter.

**Australian research on using trees for bioretention: Breen 2004, Denman 2006, Denman 2011 (all describing same experiment)**

* Trees grew equally well in soils of a wide range of saturated hydraulic conductivities, and grew better irrigated with stormwater than irrigated with tapwater.
* “Trees were grown outdoors in experimental biofiltration systems, constructed with 240mm [9.45 inch] diameter columns, cut into 600mm[23.6 inch] lengths. The constructed soil profiles were 500mm [20 inch] deep with 10% (v:v) composted green waste added to the surface 200mm [8 inch]. The three soils used were sands with saturated hydraulic conductivities (SHC) of 4, 95 and 170mm per hour [0.16, 3.75 and 6.7 inches per hour] and the soils are referred to as low, medium and high SHC soil respectively.”
* “Tree growth was similar in the three soils studied.” (Denman 2006)
* Trees grew taller and had greater root density when irrigated with stormwater compared to tapwater.
* “The low SHC soil was more effective in reducing nitrogen losses, particularly the inorganic forms.” (Denman 2006)
* “Averaged across all species, planting results in an increase in infiltration rate compared to the unplanted control.” Breen et al 2004
* See Task 2 Water Quality Draft Report for more on this experiment.

**Fassman et al 2013 Bioretention Report for New Zealand**

* 115 page report including:
* a literature review of bioretention media
* a summary of trends in how bioretention media specifications are changing over time based on recent research and experience
* research to determine best bioretention media for New Zealand.
* Summary of Fassman et al (2013) **literature review** (see their report for much more!):
* Common reasons for hydraulic failure of bioretention media include:
* “Incorrect media specification, where the media has incorrect physical/chemical properties for removing targeted pollutants.
* Incorrect media specification, where the media may have high clay content or extremely fine particles, and vulnerability to compaction which cause inadequate drainage and over-extended ponding.
* Incorrect compaction, often resulting from poor compaction specifications or using media vulnerable to compaction. The media is either under-compacted and too loose resulting in low contact time, or over-compacted and too dense resulting in inadequate drainage and over-extended ponding.
* Clogging, where excessive sediment loads restrict the pores of the media, hindering infiltration and causing inadequate drainage and over-extended ponding. Clogging most commonly occurs at the surface as crusting, capping, or sealing. Sediment from unstable catchments, catchments with active construction, or fine particles within the filter media contribute to clogging.”
* Cites that Warynski and Hunt (2011) “performed an inspection of 20 bioretention cells throughout the state. They found 82% of bioretention cell filter media having incorrect particle size distributions (PSD), and 44% of bioretention cells having incorrect permeabilities. Furthermore, 50% of bioretention cells were undersized.”
* Summarizes the following sampling of typical bioretention media composition specifications:

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Table 4.3: Recommended bioretention filter media mixes from worldwide sources1 (Fassman et al 2013)

|  |  |  |  |
| --- | --- | --- | --- |
| **Guideline** | **Aggregate** | **Organic** | **Note** |
| Auckland Regional Council (2003), Waitakere City Council (2004) | Sandy loam, loamy sand, loam, loam/sand mix (35 - 60% v/v sand) | Not specified | Clay content < 25% v/v |
| Prince George’s County, Maryland (2007) | 50 - 60% v/v sand | 20 - 30% v/v well aged leaf compost, 20 - 30% v/v topsoil2 | Clay content < 5% v/v |
| The SUDS manual (Woods-Ballard et al. 2007) | 35 - 60% v/v sand, 30 - 50% v/v silt | 0 - 4% v/v organic matter | 10 - 25% v/v clay content |
| Facility for Advanced Water Biofiltration (FAWB, 2009a) | Washed, well graded sand with specified PSD band | 3% w/w organic material | Clay content < 3% w/w, top 100 mm to be ameliorated with organic matter and fertilizer |
| Seattle Public Utilities (2008) | 60 - 65% v/v mineral aggregate, PSD limit (“clean sand” with 2 - 5% passing #200 sieve), U3 ≥ 4 | 35 - 40% v/v fine compost which has > 40% w/w organic matter content |  |
| Puget Sound Partnership (2009) |  | 40% v/v compost, or 8 - 10% w/w organic matter |  |
| North Carolina Cooperative Extension Service (Hunt & Lord 2006) | 85 - 88% v/v washed medium sand4 | 3 - 5% v/v organic matter | 8 - 12% v/v silt and clay |
| City of Austin (2011) | 70 - 80% v/v concrete sand5 | 20 - 30% v/v screened bulk topsoil2 | 70 - 90% sand content, 3 - 10% clay content, silt and clay content < 27% w/w. Warning not to use sandy loam (“red death”).6 |

1. % v/v is percent by volume; % w/w is percent by weight (mass).

2. “Topsoil” is a non-technical term for the upper or outmost layer of soil, however there is no technical standard for topsoil.

3. U, Coefficient of Uniformity = D60/D10, where D60 is particle diameter at 60% passing and D10 is particle diameter at 10% passing.

4. A specific definition for “medium sand” was not identified. ASTM D2487-10 classifies coarse-grained sands as those with > 50% retained on the (USA) No. 200 sieve (75 m) and > 50% of coarse fraction passing the No. 4 sieve (4.76 mm). Clean sands contain < 5% fines. Fine-grained soils are silts and clays whereby > 50% passes the No. 200 sieve.

5. Concrete sand is described by ASTMD2487-10 as coarse sand that is retained by a (USA) No. 10 sieve (2.00 mm)

6. “Red death” is commercially available fill material in Austin marketed as sandy loam.

* Saturated Hydraulic Conductivity:
  + - “While hydraulic conductivity initially declines as the filter media is compacted (see section 5.5), FAWB (2009a) and Barret et al. (2011) found it often recovers back to the design value over time as increased plant root growth counters the effects of compaction and clogging.”
    - Summarizes worldwide sampling of typical bioretention media hydraulic conductivity specifications in Table x:

Table 4.4: Recommended hydraulic conductivity of bioretention filter media (Fassman et al 2013)

|  |  |
| --- | --- |
| **Publication** | **Hydraulic Conductivity** |
| Auckland Council Rain Garden Construction Guide (2011) | 12.5 mm hr-1 (minimum) |
| California Bioretention TC-32 (CASQA, 2003) | 12.5 mm hr-1 (minimum) |
| City of Austin (2011) | 50.8 mm hr-1 (minimum) |
| USEPA (2004) | 12.7 mm hr-1 (minimum) |
| FAWB (2009b) | 100 - 300 mm hr-1 (temperate climates) 100 - 500 mm hr-1 (tropical climates) |
| Prince George’s County, Maryland (2007) | 12.7 mm hr-1 (minimum) |
| The SUDS manual (Woods-Ballard et al. 2007) | 12.6 mm hr-1 |
| North Carolina Cooperative Extension Service (Hunt and Lord 2006) | 25.4 mm hr-1 (for nitrogen removal) 50.8 mm hr-1 (for phosphorus, metal and other pollutant removal) |
| Puget Sound Partnership (2009) Seattle Public Utilities (2011) | 25.4 - 305 mm hr-1 |

* Particle size distribution:
  + - “Particle size distribution (PSD) is used as a gauge of a potential filter media’s hydraulic performance of a filter media in several international guidelines.”
    - “Particle Size Distribution (PSD) may be a useful gauge of the potential hydraulic performance of a filter media, but it should not be used to replace hydraulic conductivity testing.”
    - “As well as meeting gradation limits, media should be well-graded over the entire range to avoid structural collapse due to particle migration (FAWB, 2009a).”
* Compaction during construction: a worldwide sampling of specifications for compaction during construction is summarized in table x:

Table 4.5: Recommended installation methods (Fassman et al 2013)

|  |  |  |
| --- | --- | --- |
| **Jurisdiction** | **Guideline on lifts** | **Guideline on compaction** |
| Prince George’s County, (2007) | 200 to 300 mm lifts | Natural compaction with light watering |
| ARC TP10 (2003) | 300 to 400 mm lifts | Loose compaction by light tamping with backhoe bucket |
| North Shore City Council (2009) | 300 mm lifts | Natural compaction with wetting of soil |
| Melbourne (FAWB 2009b) | Two lifts if depth is over 500 mm | Light compaction; single pass with vibrating plate for small systems; single pass with roller for large systems |
| Seattle Public Utilities (2008) | Loose lifts | Compact to 85 to 90% of modified maximum dry density |
| California Stormwater (CASQA 2003) | 460 mm or greater lifts | Light compaction |

* Summary of Fassman et al (2013) **results** (see their report for much more!):
* Compaction of bioretention media:
  + - “If specific compaction details (such as water content) are not designed for, filter media may easily be over or under compacted, leading to an undesirable hydraulic conductivity and potential failure of the bioretention cell. An advantage of materials that are relatively insensitive to compaction is a greater certainty of achieving design conductivity range.”
    - “the density of predominantly sand based media are less susceptible to the effects of compaction and water content.”
* Particle Size Distribution:
  + - Mixes that met the author’s desired hydraulic conductivity range did not meet international Particle Size Distribution guidelines. The 3 that best fit their desired hydraulic conductivity range had higher fines than the recommended guidelines, while two out of three are poorly graded. The authors conclude that “With this result, it is clear the PSD-based guidelines should not be used as a substitute to hydraulic conductivity testing.”
    - “A coarse sand (all passing 2 mm, with U 3) or high silt/clay component (considered to be >20%, as might be found in natural soils) will be susceptible to the field installation compaction method, and hence so will be the hydraulic conductivity. In practice, if these materials are used, careful installation procedures and post-installation testing of infiltration and/or bulk density would be strongly recommended.”
    - “mixes that satisfied aggregate PSDs tended to produce extremely high hydraulic conductivities, even when mixed with relatively high levels of compost (which also violates many international guidelines).”
* Plant Growth Trials
  + - Because the sand based bioretention media developed in this project had low organic matter content (<10% v/v compost, equating to 1 - 3% g/g total carbon), and also had very low clay and silt components, it was expected that plants might not grow well in them because they were thought to have little ability to store and supply water and nutrients to the plants. Therefore the authors tested two of their sand based mixes for plant growth compared to a rich horticultural soil mix, containing 30% compost by volume, known to grow vigorous plants. They grew 2 bioretention plant species for 6 months in pots of each of the three soils, with a low rate of 9 month slow release fertilizer added to the sand based mixes only. No differences in plant growth or plant available water were observed between the plants growing in sand based mixes vs. the horticultural mix. They concluded that: “the volume of stored water that plants can access for growth is similar in all substrates, being 21 to 24% of the total soil volume. This is because the two commercial mixes have a large amount of water that is held very tightly (to the organic matter) and therefore inaccessible to plants… It is unlikely the three sand-based mixes developed will be any more drought prone than existing commercial mixes with high organic contents, as all store similar volumes of plant-available water per unit depth...” If these results also hold true in longer term field experiments, plants should be able to grow just as well in bioretention media with low organic matter content as in horticultural mixes designed for vigorous plant growth. Minimizing soil organic matter content is crucial to maximize nutrient reduction by bioretention systems and to minimize nutrient leaching from the soil.

**Australian guidelines for bioretention media (FAWB 2009)**

* Based on extensive research
* Requires three layers of media:
* the filter media itself (400-600 mm [15.75 to 23.62 inches] deep or as specified in the engineering design),
* a transition layer (100 mm [4 inches] deep),
* a drainage layer (50 mm [2 inches] minimum cover over underdrainage pipe).
* The biofiltration system will operate so that water will infiltrate into the filter media and move vertically down through the profile.
* “ required to support a range of vegetation types (from groundcovers to trees) that are adapted to freely draining soils with occasional wetting”
* “ The material should be based on **natural or amended natural soils** or it can be **entirely engineered**… In the case of natural or amended natural soils, the media should be a **loamy sand**.”
* “ In general, the media should have an appropriately high permeability under compaction and should be free of rubbish, deleterious material, toxicants, declared plants and local weeds (as listed in local guidelines/Acts), and should not be hydrophobic.”
* “ The filter media should contain some organic matter for increased water holding capacity but be low in nutrient content.” Requires minimum 3% organic matter by weight; does NOT specify maximum organic content, just maximum nutrient content. [Note: research in North Carolina indicates that using trees with suspended pavement and soils higher in organic matter content can still attain good nutrient reduction if soil nutrient content is below NC standards, Jonathan Page, NC State, 2013, personal communication].
* “Maintaining an adequate infiltration capacity is crucial in ensuring the long-term treatment efficiency of the system. The ability of a biofiltration system to detain and infiltrate incoming stormwater is a function of the filter surface area, extended detention (ponding) depth, and the hydraulic conductivity of the filter media. Most importantly, design of a biofiltration system should optimize the combination of these three design elements.”
* “For a biofiltration system in a temperate climate with an extended detention depth of 100 – 300 mm [*4 -12 inches]*and whose surface area is approximately 2% of the connected impervious area of the contributing catchment, the prescribed hydraulic conductivity will generally be between 100 – 300 mm/hr [*4 -12 inches/hr*] in order to meet best practice targets... This configuration supports plant growth without requiring too much land space (italics added).”

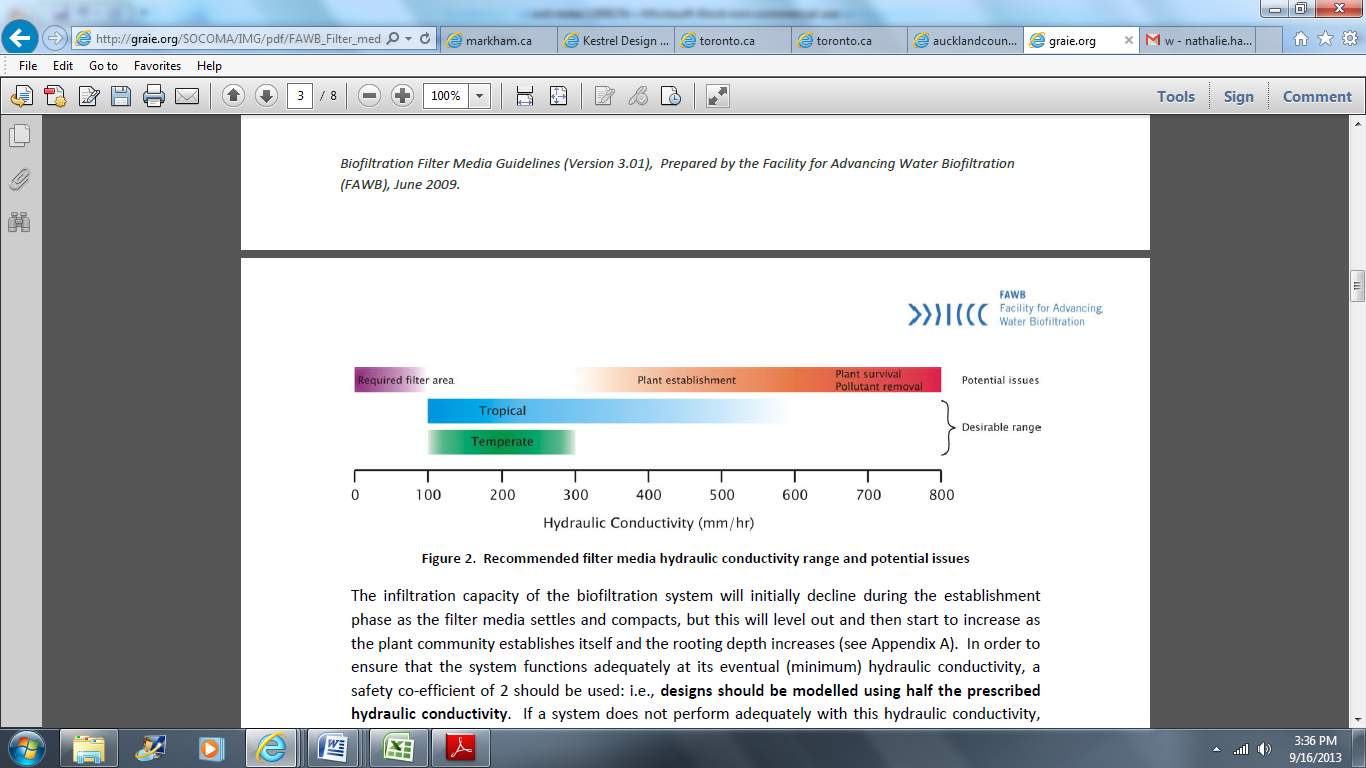
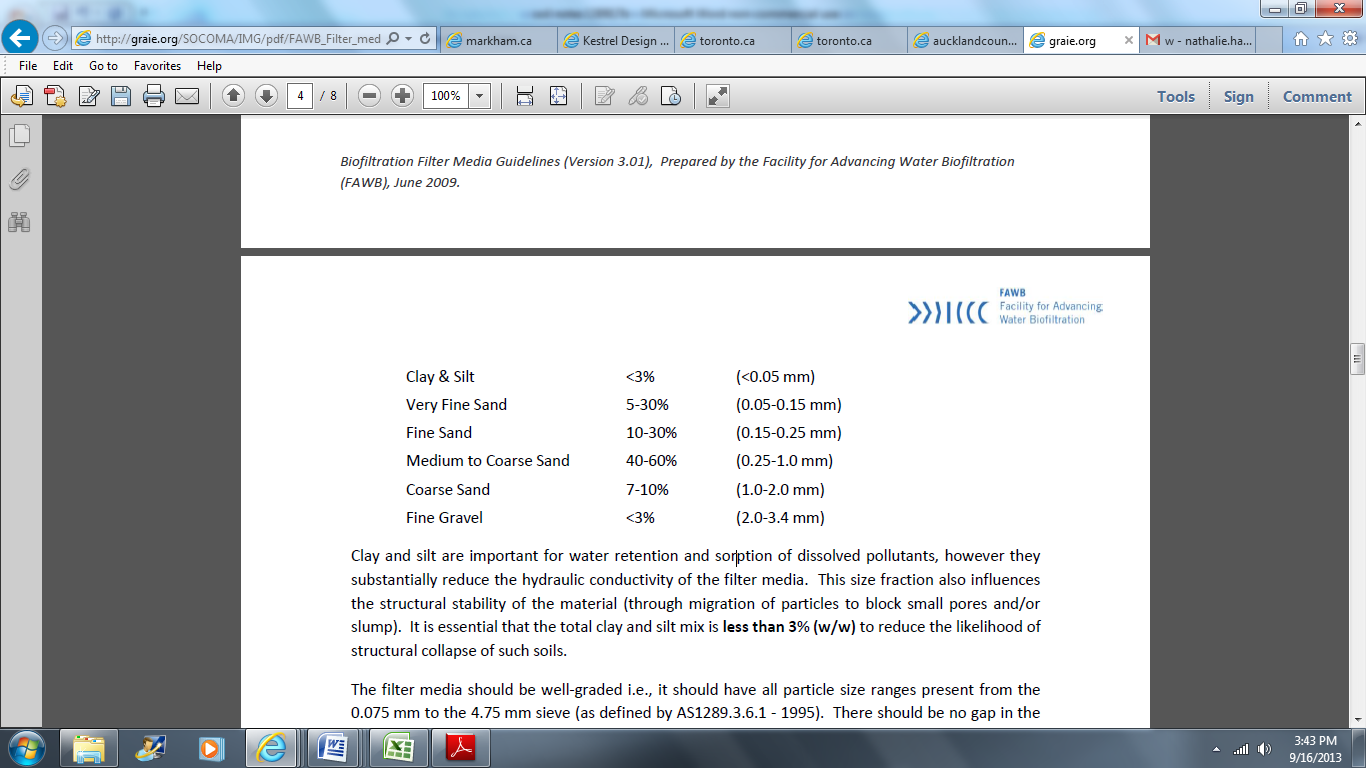


Figure 4.5: Recommended filter media hydraulic conductivity range and potential issues (FAWB 2009)

* “The infiltration capacity of the biofiltration system will initially decline during the establishment phase as the filter media settles and compacts, but this will level out and then start to increase as the plant community establishes itself and the rooting depth increases” (FAWB 2009 based on research by Hatt et al 2009).
* “The hydraulic conductivity of potential filter media should be measured using the ASTM F1815-06 method. This test method uses a compaction method that best represents field conditions and so provides a more realistic assessment of hydraulic conductivity than other test methods. Note: if a hydraulic conductivity lower than 100 mm/hr [4 inches/hr] is prescribed, the level of compaction associated with this test method may be too severe and so underestimate the actual hydraulic conductivity of the filter media under field conditions. However, FAWB considers this to be an appropriately conservative test, and recommends its use even for low conductivity media.” [*note from Kestrel team, this is the same recommendation as in Urban 2008*)
* “Particle size distribution (PSD) is of secondary importance compared with hydraulic conductivity. A material whose PSD falls within the following recommended range does not preclude the need for hydraulic conductivity testing i.e., it does not guarantee that the material will have a suitable hydraulic conductivity. However, the following composition range (percentage w/w) provides a useful guide for selecting an appropriate material:



Clay and silt are important for water retention and sorption of dissolved pollutants, however they substantially reduce the hydraulic conductivity of the filter media. This size fraction also influences the structural stability of the material (through migration of particles to block small pores and/or slump). It is essential that the total clay and silt mix is less than 3% (w/w) to reduce the likelihood of structural collapse of such soils. The filter media should be well-graded i.e., it should have all particle size ranges present from the 0.075 mm to the 4.75 mm sieve (as defined by AS1289.3.6.1 - 1995). There should be no gap in the particle size grading, and the composition should not be dominated by a small particle size range. This is important for preventing structural collapse due to particle migration.”

* “Total Nitrogen (TN) Content – <1000 mg/kg.“
* “Orthophosphate (PO43-) Content – <80 mg/kg. Soils with total phosphorus concentrations >100 mg/kg should be tested for potential leaching. Where plants with moderate phosphorus sensitivity are to be used, total phosphorus concentrations should be <20 mg/kg.“ [note from Kestrel team, this is higher than NC State recommendations]
* For engineered media, they recommend:
* “A washed, well-graded sand with an appropriate hydraulic conductivity should be used as the filter medium.”
* “The top 100 mm [4 inches] of the filter medium should then be ameliorated with appropriate organic matter, fertiliser and trace elements... This amelioration is required to aid plant establishment and is designed to last four weeks; the rationale being that, beyond this point, the plants receive adequate nutrients via incoming stormwater.” *[note from Kestrel team: this is similar to the mixes being tested in MN and WI described in task 8 of Objective 2, bioretention, in that organic matter is included only in the top 4 inches]*

1. **Recommended Soil for Trees for Stormwater**

Bioretention Soil Mix A is recommended for bioretention with trees (see guidelines below). Mixes B or C could also be used for bioretention with trees, but if mixes B or C are used, it is recommended to limit the saturated hydraulic conductivity to a maximum of 4” per hour.

Rock based structural soil may be used if volume provided conforms to tree soil volume requirements in the above soil volume specification.

**Rationale for Recommending Unscreened Topsoil Component in Bioretention Soil Mix A**

Bioretention Mix A consists of sand, unscreened topsoil, and compost per the guidelines below. It uses unscreened topsoil and recommends blending using a front end loader to preserve topsoil peds as much as possible. In an undisturbed soil, soil particles are clumped together into large units called peds. Peds range in size from the size of a large sand grain to several inches, so ped structure significantly increases pore space in the soil compared to a screened soil without peds. Pore spaces between soil peds improve air and water movement, water holding capacity, as well as root growth. Preserving ped structure is especially important in finer soils, because finer soils without ped structure have only very small pores and therefore lack permeability. Using an unscreened topsoil and preserving ped structure as much as possible allows for a higher clay content in Bioretention Soil Mix A compared to typical bioretention mixes because the ped structure maintains pore space and infiltration rates despite the higher clay content. The higher clay and silt content (25-40% by dry weight) is beneficial because it provides higher cation exchange capacity (for increased nutrient retention beneficial for plant growth and for increased pollutant removal) and higher water holding capacity (beneficial for plant growth).

Table 4.6: Comparison of Pros and Cons of Bioretention Soil Mixes A-C

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Mix** | **Current Composition** | **Proposed Updated Composition\*** | **Pros** | **Cons** |
| A | Not currently in MN Stormwater Manual | All components below by dry weight:  60-75% sand  Min. 55% total coarse and medium sand as a % of total sand  Less than 12% fine gravel less than 5 mm (Calculated separately from sand/silt/ clay total)  2 to 5 % organic matter  P content between 12 and 36 mg/kg per Mehlich III test | Best for pollutant removal, moisture retention, and growth of most plants; less likely to leach P than mix B because of low P content | Harder to find.  Research in Wisconsin indicates that in cold climates, excess of sodium ions can promote displacement of Mg and Ca in the soil, which breaks down soil structure and decreases infiltration rate, and can also cause nutrient imbalances\*\* |
| B | 50-70% construction sand  30-50% organic leaf  compost | 70-85% construction sand  15-30% organic leaf  compost | Easy to mix; least likely to clog | Likely to leach P, lack of fines in mix results in less dissolved pollutant removal; harder on most plants than mix A because it dries out very quickly |
| C | Not currently in MN Stormwater Manual | 85-88 percent by volume sand and  8 to 12 percent fines by volume,  3 to 5 percent organic matter by dry weight  P content between 12 and 36 mg/kg per Mehlich III test | Likely to sorb more dissolved P and metals than mix B because it contains some fines; less likely to leach P than mix B because of low P content; | Harder on most plants than mix A because it dries out very quickly. Research in Wisconsin indicates that in cold climates, excess of sodium ions can promote displacement of Mg and Ca in the soil, which breaks down soil structure and decreases infiltration rate, and can also cause nutrient imbalances\*\* |

\* See soil guidelines for important specifics about soil components and other important parameters

\*\* This problem can be avoided by minimizing salt use. Sodium absorption ratio can be tested, if sodium adsorption ratio becomes too high, additions of gypsum (calcium sulfate) can be added to the soil to free the sodium and allow it to be leached from the soil (Pitt et al in press).

**GUIDELINES FOR BIORETENTION SOIL MIX A**

The following guidelines are written in a format similar to a specification, and can serve as a basis for a specification, however, they are NOT a finished specification. Any specification for construction must be developed specifically for that project by a person skilled in writing specifications and construction documents. Additional items are needed particularly in Part One – General. Terminology and requirements in the final specifications must be consistent with the terminology in other parts of the construction documents including plans and detail nomenclature.

Part 1 GENERAL

Revise this Section by deleting and inserting text to meet Project-specific requirements.

This Section uses the term "Architect." Change this term to match that used to identify the design professional as defined in the General and Supplementary Conditions.

Verify that Section titles referenced in this Section are correct for this Project's Specifications; Section titles may have changed.

* + - 1. DEFINITIONS
         1. Clay, silt and sand soil particles: Per USDA size designations. It is critical NOT to use testing laboratories that report results in engineering size designations such as the Unified or AASHTO systems.
         2. Coarse Sand: Process washed and graded sand from regional sand suppliers. Coarse Sand will be further defined in Part 2 - Products.
         3. Compost: Decomposed plant based biomass. Compost will be further defined in Part 2 - Products.
         4. Bioretention Soil Mix A: A mixture of Topsoil, Coarse Sand and Compost intended to fill bio- retention planters to support the treatment of storm water and the growth of trees and other plants. Bioretention Soil Mix A will be further defined in Part 2 - Products.
         5. Screened Soil: Any soil run through any type of screen with a mesh size 3” square or smaller.
         6. Soil Cells: also called structural cells; pre-engineered structural system to hold up the sidewalk and be filled with soil to support tree roots and treat storm water. Soil Cells will be further defined in Part 2 - Products.
         7. Soil Peds: Clumps of soil that naturally aggregate during the soil building process.
         8. Structural Soil: A mixture of stone and soil formulated to be compacted to 95% of maximum dry density, Standard Proctor and support tree roots. Structural Soil will be further defined in Part 2 - Products.
         9. Topsoil: Fertile, friable, loamy soil, harvested from natural topsoil sources, Topsoil will be further defined in Part 2 - Products
      2. SUBMITTALS
         1. Soil test analysis: Submit soil testing results from an approved soil-testing laboratory for each soil mix for approval. Soil suppliers that regularly prepare Bioretention Soil Mix A that meets these requirements may submit past testing of current production runs to certify that the mix to be supplied meets the requirements provided the testing results are less than 12 months prior to the submission date.
  1. The testing laboratory shall be a member of the Soil Science Society of America's, North American Proficiency Testing Program (NAPT). The testing lab shall specialize in agricultural soil testing. Geotechnical engineering soil testing labs are not acceptable.
  2. Testing shall comply with the requirements of the Methods of Soil Analysis Part 1 and 3, published by the Soil Science Society of America or the ASTM testing required.
  3. Testing of topsoil and Bioretention Soil Mix A shall be required as defined below:

a. Physical analysis.

1. USDA particle size analysis shall be include, gravel, clay, silt, and coarse, medium and fine sand fractions.

2. Hydraulic Conductivity testing (Bioretention Soil Mix A only) using ASTM F1815 at 80% AND 85% compaction at proctor density (ASTM D 698-91).

This is a **LABORATORY TEST** to determine water flow at specified compaction rates. Laboratories that provide this testing include:

Hummel Soil Labs, [www.turfdoctor.com](http://www.turfdoctor.com); (607) 387-5694,35 King Street, PO Box 606, Trumansburg, NY, 14886.

Turf Diagnostics & Design, [www.turfdiag.com](http://www.turfdiag.com); (913)-723-3700, 613 E. 1st Street, Linwood, KS, 66052.

b. Chemical analysis. Note that nutrient levels and chemical analysis shall include recommendations from the testing laboratory for ranges of each element appropriate for the types of plants to be grown in the soil mix.

1. Nutrient levels by parts per million including phosphorus, potassium, calcium, magnesium, manganese, iron, copper, zinc and calcium

2. Percent organic content

3. pH

4. Soluble salt by electrical conductivity

5. Cation Exchange Capacity (CEC)

* + 1. Chemical analysis shall be interpreted by the Owner based on plant material specified and testing recommendations.
       - 1. Product Data: For each type of product including; Soil Cells, Structural Soil, Coarse Sand and Compost, submit manufacturer's product literature with technical data sufficient to demonstrate that the product meets the requirements of the specification.
         2. Samples for Verification: Submit one gallon minimum samples for the Coarse Sand, Compost, Topsoil, Bioretention Soil Mix A and Structural Soil. Label samples to indicate product name, source and contractor. Samples will be reviewed for appearance only. Delivered materials shall closely match the samples.
         3. Cone Penetrometer reading certification: Submit for approval, a written certification that the Bioretention Soil Mix A was sufficiently compacted to fall within the required resistance ranges. The Owner may verify the certification prior to approval.
       1. BIORETENTION SOIL MIX A COMPACTION TESTING
          1. Bioretention Soil Mix A shall be tested in-situ with a cone penetrometer, to the full depth of the installed soil profile or 30 inches deep, whichever is less. This is a field test to confirm correct compaction. One test shall be performed approximately once every 300 square feet of Bioretention Soil Mix A surface area. The cone penetrometer shall be available at the project site at all time when the contractor is working.
          2. Maintain a volumetric moisture meter on site to verify that moisture readings were within the required ranges during the installation and testing.
          3. The cone penetrometer shall be “Dickey-John Soil Compaction Tester”, or “AgraTronix Soil Compaction Meter,” both distributed by Ben Meadows [www.benmeadows.com](http://www.benmeadows.com)
          4. The contractor shall certify that penetration resistance readings meet the requirements. The contractor’s penetrometer shall be made available to the owner, at all times, to confirm resistance readings.
       2. SCHEDULING
          1. Schedule all utility installations prior to beginning work in this section.
       3. DELIVERY, STORAGE, AND HANDLING

When warranties are required, verify with Owner's counsel that special warranties stated in this article are not less than remedies available to Owner under prevailing local laws.

* + - * 1. Bulk Materials: Do not deliver or place backfill, soils and soil amendments in frozen, or when the material is overly wet defined as the material sticks to the hand when squeezed.

Retain subparagraph below for bare-root stock if required; this is not an ANSI Z60.1 requirement.

Provide protection including tarps, plastic and or matting between all bulk materials and any finished surfaces sufficient to protect the finish material.

* + - * 1. Provide erosion-control measures to prevent erosion or displacement of bulk materials and discharge of soil-bearing water runoff or airborne dust to adjacent properties, water conveyance systems, and walkways. Provide sediment control to retain excavated material, backfill, soil amendments and planting mix within the project limits as needed.
      1. PROJECT CONDITIONS

THIS SECTION NOT NEEDED THIS SECTION NOT NEEDED THIS SECTION NOT NEEDED THIS SECTION NOT NEEDED When warranties are required, verify with Owner's counsel that special warranties stated in this article are not less than remedies available to Owner under prevailing local laws.

* + - * 1. Weather Limitations: Do not proceed with work when sub grade soil is frozen, or is overly wet defined as the sub grade material sticks to the hand when squeezed.
      1. EXCAVATION AROUND UTILITIES
         1. Contractor shall carefully examine the civil, record, and survey drawings to become familiar with the existing underground conditions before digging. Notification of *Local Utility Locator Service* is required prior to all excavation.

Part 2 – Products

2.1 COARSE SAND

1. Coarse sand, ASTM C-33 Fine Aggregate, with a Fines Modulus Index of 2.8 and 3.2.

Sands shall be clean, sharp, natural sands free of limestone, shale and slate particles.

Sand pH shall be lower than 7.5

Provide the following particle size distribution:

Sieve size % Passing

3/8” 100

#4 95-100

#8 80-100

#16 50-85

#30 25-60

#50 5-30

#100 4-10

#200 2-4

* + - * 1. Submittals shall be completed per Part 1 - Section – Submittals for approval.

2.2 COMPOST

Compost shall meet the requirements of the US Composting Council “Landscape Architecture/Design Specifications for Compost Use”, section “Compost as a Landscape Backfill Mix Component”, with the following additional requirements:

Compost feedstock shall be yard waste trimmings and/or source-separated municipal solid waste to produce fungi-dominated compost. Compost shall not be derived from biosolids or industrial residuals.

Compost physical appearance: Compost shall be dark brown approximately the color of a 70% dark chocolate bar or darker. Particles of compost when broken shall be the same color inside as outside.

Compost odor: Compost shall have a strong, sweet, aerobic odor indicating active biological activity. Compost with a sour anaerobic odor (indicating composting in excessive water) or an odor similar to denatured alcohol (indicating incomplete composting) shall be rejected

* + - * 1. Compost testing and analysis:Compost analysis shall be provided by the Compost supplier. Before delivery of the Compost, the supplier must provide the following documentation:

A statement that the Compost meets federal and state health and safety regulations.

Compost testing methodologies and sampling procedures shall be as provided in Test methods for the Examination of Composting and Compost (TMECC), as published by the US Composting Council.

* + - * 1. Submittals shall be completed per Part 1 - Section – Submittals for approval.

2.3 TOPSOIL

1. Topsoil texture shall be a naturally produced soil of loam, sandy loam to sandy clay loam, within the following parameters, and suitable for the germination of seeds and the support of vegetative growth.
2. Topsoil may contain up to 5% by volume stones, roots or masonry debris. Topsoil shall not contain metal debris, glass other sharp objects. Topsoil shall not contain any chemicals at levels that are harmful to plants, fish or exceed EPA limitations for human contact.
3. Topsoil should not be screened or processed in a manner that breaks down soil peds. Soil peds of 2 inches in diameter or greater should be visible throughout the source pile.
4. Manufactured topsoil where sand or compost has been added to a soil material to meet the specification shall be rejected. Clumps or peds of soil within the sample shall be the same color and texture on the inside as the outside of the clump or ped.
5. Physical Parameters

Parameter Units Acceptable Range

Gravel % by volume Less than 10%

Sand % by volume 30-70%

Silt % by volume 10-50%

Clay % by volume 10-25%

1. Chemical Parameters

Parameter Units Acceptable Range

Organic Matter % Dry Weight 2-8%

pH pH Units 5.0 to 7.3  
Phosphorous Sufficient to meet the maximum

requirements in the Plant/Bio-retention

Mix once the other products are added

to the mix

1. Submittals shall be completed per Part 1 - Section – Submittals for approval.

2.4 BIORETENTION SOIL MIX A

1. Bioretention Soil Mix A soil shall be a mixture of Coarse Sand, Compost and Topsoil in proportions which meet the following parameters:

Parameter Units Acceptable Range

Silt and Clay combined % by dry weight 25-40%

Total sand % by dry weight 60-75%

Total coarse and medium sand % by dry weight Minimum of 55%

as a % of total sand

Fine gravel less than 5mm % by dry weight up to 12%

Calculated separately from

Sand/silt/ clay total

Organic matter content % Loss on ignition by dry weight 2-5%

Saturated Hydraulic conductivity Inches per hour 1-4” hour

ASTM F1815 at 85% compaction

Standard Proctor ASTM D968

Phosphorus PPM Between 12 and 36

Cation Exchange capacity meq/g More than 10

1. The following are suggested mix ratio ranges.  It is understood that compost quality and particle size, coarse sand shape and variations in particle distribution , topsoil component, and silt / clay amounts within the tolerance will cause the soil blend within these suggested mix ratio ranges to drain too fast or too slow.  The contractor shall adjust the final mix proportions to achieve the required drainage rate and % organic matter.  Any variation of required products, above or below the percentages listed below, needed to attain the required drainage rate or %organic matter, shall not be grounds to change the agreed upon price of the installed material.

Approximate ranges by volume

Coarse Sand 50-65%

Topsoil 25-35%

Compost 10-15%

1. Lightly mix the Bioretention Soil Mix A using a front end loader to preserve topsoil peds as much as possible. Topsoil peds 2” in diameter or larger should be visible in the finished stockpile. Do not over mix or screen the material.
2. Submittals shall be completed per Section 1.4 and shall be interpreted by Owner based on plant material specified and testing recommendations.

2.5 STRUCTURAL SOIL:

A. A mixture of stone and soil formulated to be compacted to 95% of maximum dry density, Standard Proctor and support tree roots. Stone shall not be limestone.

B. Structural Soil shall be “CU Soil” as manufactured by Amereq, Inc New York City, NY, or approved equal.

C. Submittals shall be completed per Section 1.4.

2.6 SOIL CELLS:

Pre-engineered modular structures designed to hold up pavement and to be filled with soil to support tree roots and treat storm water, with the goal of protecting soil within the cells from compaction from the loads on the overlying pavement. Soil Cells shall be capable of supporting loads up to and including AASHTO H-20, when used in conjunction with approved pavement profiles.

B. Soil Cells shall meet the following requirements:

1. The structure design shall permit an un interrupted mass of soil throughout the structure. All openings between different cell units shall have a minimum area of 140 square inches to permit: a continuous mass of soil that allows for capillary transfer of water; fosters the growth of large tree roots including the zone of rapid taper roots that can become up to 12” in diameter at tree maturity; and permits the structure to be built around, over; under and thru existing and proposed utilities.

2. Each cell stack shall be structurally independent of all adjacent stacks such that the cell layout can achieve maximum layout flexibility.

3. The structure shall permit damp soils with large soil peds to be installed and the soil installed without vibrating the structure. The structural openings must allow all the soil to be checked for compaction and complete filling of all cell areas.

4. The Soil Cell deck shall be perforated to allow the free flow of water thru the deck.

C. Soil cell installation shall include all accessories, geotextiles, geogrids, and aggregate layers required by the Soil Cell manufacture.

D. Submittals shall be completed per Section 1.4.

Part 3 - Execution

3.1 SITE EXAMINATION

A. Examine the surface grades and soil conditions for any circumstances that might be detrimental to soil drainage.

3.2 SITE PREPARATION

A. Excavate to the proposed sub grade. Maintain all required angles of repose of the adjacent materials as shown on the drawings or as required to support adjacent materials or structures. Do not over excavate into compacted sub grades of adjacent pavement or structures. Remove all construction debris and material.

B. Confirm that the sub grade is at the proper elevation and compacted as required. Sub grade elevations shall slope parallel to the finished grade and/or toward the subsurface drain lines as shown on the drawings.

C. Protect adjacent walls, walks and utilities from damage or staining by the soil. Use ½” plywood and or plastic sheeting as directed to cover existing concrete, metal and masonry work and other items as directed during the progress of the work.

1. Clean up any soil or dirt spilled on any paved surface, including at the end of each working day.

3.3 SOIL CELL INSTALLATION

A. Install Soil Cells in accordance with the manufacturers requirements including all accessories, geotextile, geogrid, and aggregate layers.

3.4 BIORETENTION SOIL MIX A INSTALLATION

A. Loosen or till the subsoil of the sub grade to a depth of 2-3 inches, or as required, with a backhoe or other suitable device.

1. Where required on the drawings or other requirements, loosen the subsoil to a depth of 18-24 inches below the required subgrade elevation to improve infiltration into the subgrade soil. Loosen the soil using a backhoe by digging into the subgrade soil and lifting then dropping the soil in place. Do not over work the soil or break up the large clumps in the soil created by the process. Do not allow the loosened soil to become re-compacted by other work.

B. Install all required drainage aggregate and drain lines.

C. Install Bioretention Soil Mix A in approximately 12 inch lifts to the required depths. Lightly compact each lift with a maximum of two passes with a 5 HP vibrating plate tamper to achieve the required penetration resistance. Maintain volumetric soil moisture during installation and compaction at between 5 and 15%.

D. Scarify the surface of each lift with the teeth of a back hoe or similar equipment prior to installing additional lifts.

E. Do not drive over delivered soil to spread or grade. Install soil in narrow bands, working out from the installed soil such that soil delivery and spreading equipment does not have to pass over previously installed soil. The width of each band of installed soil shall not exceed the reach of the delivery equipment.

F. Coordinate the installation of water harvesting distribution and drain lines within the Bioretention Soil Mix A.

G. Install soil in Soil Cells according to the cell manufacturer’s requirements.

H. Grade the finished surface of the Bioretention Soil Mix A to the grades indicated on the drawings plus extra soil for settlement as noted below.

1. The Bioretention Soil Mix A when properly installed at the compaction levels indicated will continue to settle. It is not the intent of these requirements to construct a soil profile that is immediately stable. Add an additional 1 inch of soil for each 10 inches of installed soil depth. The grades shown on the drawings are the grades after the anticipated settlement.

2. The tolerance for finished grades shall be plus or minus ½ inch in 10 feet.

3.5 BIORETENTION SOIL MIX A COMPACTION

A. Compact the Bioretention Soil Mix A so that the pressure reading of a cone penetrometer is between 75 and 200 psi with the volumetric soil moisture between 5 and 15%.

3.6 STRUCTURAL SOIL INSTALLATION:

A. Install and compact Structural Soil in accordance with the manufactures requirements.

3.7 CLEAN UP

### A. Once installation is complete, remove any excess soil and trash from pavements, structures or fixtures. Remove any spilled oil or other stains on surfaces caused by the work.

3.8 PROTECTION

A. Protect work and materials from damage including: compaction, contamination, and erosion including due to operations by other Contractors or trespassers. Repair all damage and loosen compaction prior to acceptance.

3.9 REPAIR OF SETTLED BIORETENTION SOIL MIX A

### A. At the end of twelve months after the date of substantial completion of the Bioretention Soil Mix A installation work, inspect the site and restore any areas where the grades have settled beyond the elevations shown on the drawings by an amount greater than 5% of the soil depth.

**REFERENCES**

Bakker. J.W. 1983. Groeiplaats en watervoorziening van straatbomen. Groen, 39(6)205-207; OBIS, 1988. Bomen in straatprofielen – Voorbeelden – Groeiplaatsberekening. Uitgeverij van de Vereniging van de Nederlandse gemeenten, ‘s-Gravenhage 1988. 63 p. Cited in Kopinga 1991.

Barret, M., Limouzin, M., & Lawler, D. (2011). Performance Comparison of Biofiltration Designs. World Environmental and Water Resources Congress 2011 (pp. 395-404).

Bassuk, Nina. 2010. Using CU-Structural Soil to Grow Trees Surrounded by Pavement. InThe Great Soil Debate Part II: Structural soils under pavement. ASLA Annual Meeting Handout. Available August 2013 from <http://www.asla.org/uploadedFiles/CMS/Meetings_and_Events/2010_Annual_Meeting_Handouts/Sat-B1The%20Great%20Soil%20Debate_Structural%20Soils%20Under%20Pavement.pdf>

DTAH, Lead Consultant, ARUP, Engineering, and James Urban, Urban Trees + Soils

Urban Forest Innovations, Arborist. 2013. Tree Planting Solutions in Hard Boulevard Surfaces Best Practices Manual. Project # A21065. Prep.ared for: City of Toronto.

Facility for Advancing Water Biofiltration (FAWB), 2009. Biofiltration Filter Media Guidelines (Version 3.01) Downloaded August 2013 from <http://graie.org/SOCOMA/IMG/pdf/FAWB_Filter_media_guidelines_v3_June_2009-2.pdf>

Fassman, EA, Simcock, R, Wang, S, (2013). [Media specification for stormwater bioretention devices, Prepared by Auckland UniServices for Auckland Council. Auckland Council technical report, TR2013/011](http://www.google.com/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=1&ved=0CCoQFjAA&url=http%3A%2F%2Fwww.aucklandcouncil.govt.nz%2FEN%2Fplanspoliciesprojects%2Freports%2Ftechnicalpublications%2FDocuments%2Ftr2013011mediaspecificationforstormwaterbioretentiondevices.pdf&ei=5F0fUuP_L-qK2wWqtYGwDg&usg=AFQjCNFp3kcfmdW_Go5LUhekP76T0n_2Yw&sig2=lDEFut2QUvSiA8P6nayUJg&bvm=bv.51495398,d.aWM). Downloaded August 2013 from <http://www.google.com/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=1&ved=0CCoQFjAA&url=http%3A%2F%2Fwww.aucklandcouncil.govt.nz%2FEN%2Fplanspoliciesprojects%2Freports%2Ftechnicalpublications%2FDocuments%2Ftr2013011mediaspecificationforstormwaterbioretentiondevices.pdf&ei=5F0fUuP_L-qK2wWqtYGwDg&usg=AFQjCNFp3kcfmdW_Go5LUhekP76T0n_2Yw&sig2=lDEFut2QUvSiA8P6nayUJg&bvm=bv.51495398,d.aWM>

Helliwell, D.R. 1986. The Extent of Tree Roots, Arboriculture Journal 10:341-347; updated in Letter to the Editor Arboricultural Journal: The International Journal of Urban Forestry, [Volume 16](http://www.tandfonline.com/loi/tarb20?open=16#vol_16), [Issue 2](http://www.tandfonline.com/toc/tarb20/16/2), 1992.

Hinman, C., and B. Wulkan. 2012. Low Impact Development. Technical Guidance Manual for Puget Sound. Publication No. PSP 2012-3.

Jenkins, J. K. G., Wadzuk, B. M., & Welker, A. L. (2010). Fines Accumulation and Distribution in a Storm-Water Rain Garden Nine Years Postconstruction. Journal of Irrigation and Drainage Engineering, 136(12), 862.

Kent, D., S. Shultz, T. Wyatt, and D. Halcrow. 2006. Soil Volume and Tree Condition in Walt Disney World Parking Lots. Landscape Journal 25:1–06

Kopinga, J. 1991. The Effect of Restricted Volumes of Soil on the Growth and development of Street Trees. Journal of Arboriculture 17(3): 57-63

Li, H., & Davis, A. P. (2008b). Urban Particle Capture in Bioretention Media. I: Laboratory and Field Studies. Journal of Environmental Engineering, 134(6), 409.

Lindsey, P. and N. Bassuk. 1991. Specifying Soil Volumes to Meet the Water Needs of Mature Urban Street Trees and Trees in Containers. Journal of Arboriculture 17(6): 141-149.

Loh, F. C. W.; Grabosky, J. C.; Bassuk, N. L. (2003) Growth Response of Ficus Benjamina to Limited Soil Volume and Soil Dilution in a Skeletal Soil Container Study. In [Urban For. Urban Gree.](http://www.sciencedirect.com/science/journal/16188667) [2 (1](http://www.sciencedirect.com/science?_ob=PublicationURL&_tockey=%23TOC%2320204%232003%23999979998%23527128%23FLP%23&_cdi=20204&_pubType=J&view=c&_auth=y&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=a680fc9c8ac6c3e8d49b58256d10024a)) 53-62.

Pitt, R., S. Clark, P. Johnson, and J. Voorhees. In Press. Evapotranspiration and Related Calculations for Bioretention Devices. CHI Monograph 14 Available October 2013 from <http://rpitt.eng.ua.edu/Class/StormWaterManagement/Fall%202009/Pitt_Evapo_final__copy_changes_accepted.pdf>

Schoenfeld, P.H. 1975. De groei van Hollandse iep in the kustprovincies van Nederalnd. Nederlands Bosbouw Tijdschrift 47:87-95. Cited in Kopinga 1991.

Schoenfeld, P.H., J. van den Burg. 1984. Voortijdige bladval en groeiafname bij ‘Heidemij’populier in beplantingen langs autowegen. Nederlands Bosbouw Tijdschrift 56:12-21. Cited in Kopinga 1991.

Smiley, E. T. 2013. Bartlett Tree Research Lab, Charlotte North Carolina, Adjunct Professor Clemson Univ., unpublished data.

Smiley, E. Thomas, Lisa Calfee, Bruce R. Fraedrich, and Emma J. Smiley. 2006. Comparison of Structural and Noncompacted Soils for Trees Surrounded by Pavement. Arboriculture & Urban Forestry 32(4): 164-169.

Urban, J. 1992. Bringing Order to the Technical Dysfunction Within the Urban Forest. Journal of Arboriculture 18(2): 85-90.

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1. Tree quality includes information specific to a tree, such as branch width, canopy extent and wound size. Soil characteristics include information pertaining to soil type and soil volume. Planting characteristics relate to information pertaining to the tree planting, such as information on the position of the root ball and use of mulch during planting. [↑](#footnote-ref-1)